AN679

Temperature Sensing Technologies

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INTRODUCTION

Of all of the sensing technologies, temperature sensing is the most common. This phenomena can be explained by citing examples in a multitude of applications where knowing and using the actual or relative temperature is critical. For instance, other sensors such as pressure, force, flow, level, and position many times require temperature monitoring in order to insure accuracy. As an example, pressure and force are usually sensed with resistive Wheatstone bridge configurations. The temperature errors of the resistive elements of these bridges can exceed the actual measurement range of the sensor, making the pressure sensor's output fairly useless, unless the temperature of the bridge is known. Flow and level sensor accuracies are dependent on the density of the liquid or gas.

One variable that affects the accuracy of these sensors is the temperature of that material. Position is most typically used in motor control. In these circuits, temperature affects the efficiency of the motor. Consequently, the understanding of temperature sensing is needed in order to fully understand how to accurately sense most other physical phenomena.

This application note will cover the most popular temperature sensor technologies to a level of detail that will give the reader insight into how to determine which sensor is most appropriate for the application. This note is written from the perspective of catering to the complex issues of the sensing environment and required accuracy. Once the sensor is selected, subsequent Microchip application notes can be used to design appropriate microcontroller interface circuits. These circuits will offer the complete signal path from the low level output signals of the sensor, through the analog signal conditioning stages to the microcontroller. Techniques such as sensor excitation, sensor signal gain, and digital linearization are reserved for these further discussions.

SO MANY TEMPERATURE SENSORS

The most popular temperature sensors used today are the Thermocouple, Resistive Temperature Device (RTD), Thermistor, and the newest technology, the Integrated Silicon Based Sensors. There are other sensing technologies, such as Infrared (Pyrometers) and Thermal Pile. These alternatives are beyond the scope of this application note.

Each of these sensor technologies cater to specific temperature ranges and environmental conditions. The sensor's temperature range, ruggedness, and sensitivity are just a few characteristics that are used to determine whether or not the device will satisfy the requirements of the application. No one temperature sensor is right for all applications. The thermocouple's wide temperature range is unrivalled as is the excellent linearity of the RTD and the accuracy of the Thermistor.

Table 1 summarizes the main characteristics of these four temperature sensors. This table can be used during the first pass of the sensor selection process. Further details concerning the construction and characteristics of these sensors are given in the following sections of this application note

To complement the specifications sited in Table 1, a list of typical applications for these four temperature sensors are shown in Table 2.

	Thermocouple	RTD	Thermistor	Integrated Silicon
Temperature Range	–270 to 1800°C	–250 to 900 °C	–100 to 450°C	-55 to 150°C
Sensitivity	10s of μV / ˚C	0.00385 Ω / Ω / ˚C (Platinum)	several Ω / Ω / ˚C	Based on technology that is -2mV/°C sensitive
Accuracy	±0.5°C	±0.01°C	±0.1°C	±1°C
Linearity	Requires at least a 4th order polynomial or equivalent look up table.	Requires at least a 2nd order polynomial or equivalent look up table.	Requires at least 3rd order polynomial or equivalent look up table.	At best within ±1°C. No linearization required.
Ruggedness	The larger gage wires of the thermocouple make this sensor more rugged. Additionally, the insulation materials that are used enhance the thermocouple's sturdiness.	RTDs are susceptible to damage as a result of vibration. This is due to the fact that they typically have 26 to 30 AWG leads which are prone to breakage.	The thermistor element is housed in a variety of ways, however, the most stable, hermetic Thermistors are enclosed in glass. Generally thermistors are more difficult to handle, but not affected by shock or vibration.	As rugged as any IC housed in a plastic package such as dual-in-line or surface outline ICs.
Responsiveness in stirred oil	less than 1 Sec	1 to 10 Secs	1 to 5 Secs	4 to 60 Secs
Excitation	None Required	Current Source	Voltage Source	Typically Supply Voltage
Form of Output	Voltage	Resistance	Resistance	Voltage, Current, or Digital
Typical Size	Bead diameter = 5 x wire diameter	0.25 x 0.25 in.	0.1 x 0.1 in.	From TO-18 Transistors to Plastic DIP
Price	$1 to $50	$25 to $1000	$2 to $10	$1 to $10

TABLE 1: *The most common temperature sensors in industry are the thermocouple, RTD, thermistor, and integrated silicon based. No one temperature sensor is right for all applications. The thermocouple's wide temperature range is unrivalled as is the excellent linearity of the RTD and the accuracy of the thermistor. The silicon sensor is easy to implement and install in a circuit.*

Sensor Type	Application
Thermocouple	Extremely high temperature sensing, biophysics, metal cutting research, gas chromatography, internal combustion engine temperatures, chemical reactions
RTD	Cold junction compensation, bridge temperature, calibration, process control.
Thermistor	Cold junction compensation, bridge temperature sensing, pyrometer calibration, vacuum manometers, anemometers, flow meters, liquid level, fluid velocity, thermal conductivity cells, gas chromatography
Silicon Based	Cold junction compensation, personal computers, office electronics, cellular phones, HVAC, battery management, four speed controls

TABLE 2: *Listed are some examples of the applications that each temperature sensor is best suited for.*

THE VERSATILE, INEXPENSIVE THERMOCOUPLE

The thermocouple consists of two wires of dissimilar metals that are soldered together at one end as shown in Figure 1. The temperature at the Reference Junction (also know as the Cold Junction Compensation Point) is used to negate the errors contributed by the Iron-Copper and Constantan-Copper junctions. The connecting point of the two metals of the thermocouple is positioned on the target where the temperature measurement is needed.

This configuration of materials produces a voltage between the two wires at the unsoldered end that is a function of the temperature of all of the junctions. Consequently, the thermocouple does not require voltage or current excitation. As a matter of fact, an attempt to provide either type of excitation could introduce errors into the system.

Since a voltage develops at the open end of the two dissimilar wires, it would seem as if the thermocouple interface could be done in a straight forward manner by measuring the voltage difference between the wires.

This could easily be the case if it wasn't for the fact that the termination ends of the thermocouple wires connect to another metal, usually copper.

This creates another pair of thermocouples, which introduces a significant error to the system. The only way to negate this error is to sense the temperature at the Reference Junction box (Figure 1) and subtract the contributing errors of these connections in a hardware solution or a combination of software and hardware.

Pure hardware calibration techniques are more limited in terms of linearization correction than the combination of software and hardware techniques. Typically, an RTD, Thermistor, or Integrated Silicon Sensor is used to sense this junction temperature accurately.

In principle the thermocouple can be made from any two metals, however, in practice standard combinations of these two metals have been embraced because of their desirable qualities of linearity and their voltage magnitude drop versus temperature. These common thermocouple types are E, J, T, K, N, S, B, and R (summarized in Table 3 and Figure 2).

Thermocouples are highly non-linear and require significant linearization algorithms, as will be discussed later. The Seebeck Coefficient in Table 3 represents the average drift of the specific thermocouple at a specific temperature.
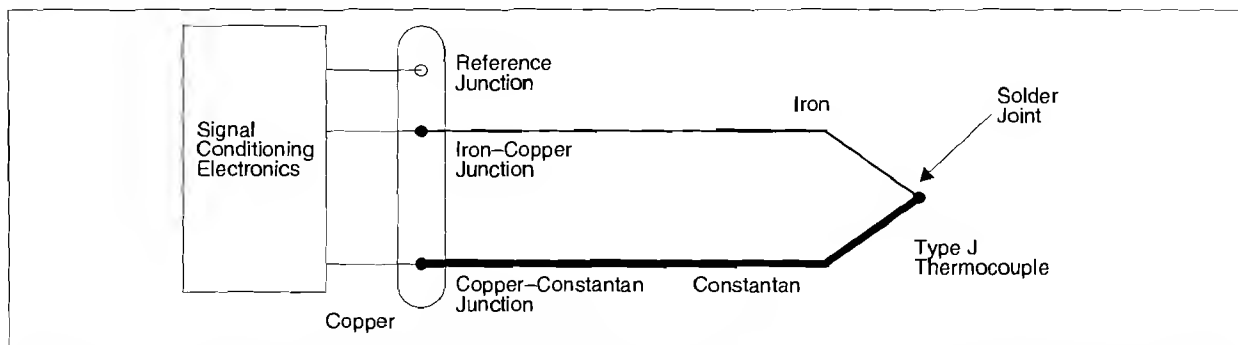
FIGURE 1: A thermocouple is constructed of two dissimilar metals, such as the Iron and Constantan in this Type J thermocouple. The temperature of the Reference Junction Compensation (also known as the Cold Junction Compensation or Isothermal Block) is used to negate the errors contributed by the Iron-Copper and Constantan-Copper Junctions.

Thermocouple Type	Conductors	Temperature Range (°C)	Seebeck Coefficient	Application Environments
E	Chromel, Constantan	-200 to 900	60μV/°C	oxidizing, inert, vacuum
J	Iron, Constantan	0 to 760	51μV/°C	vacuum, oxidizing reducing, inert
T	Copper, Constantan	–200 to 371	40μV/°C	corrosive, moist, subzero
K	Chromel, Alumel	-200 to 1260	40μV/°C	completely inert
N	Nicrosil, Nisil	0 to 1260	38μV/°C	oxidizing
S	Platinum(10% Rhodium), Platinum	0 to 1480	11μV/°C	oxidizing, inert
B	Platinum (30% Rhodium) Platinum (6% Rhodium)	0 to 1820	8μV/°C	oxidizing, inert
R	Platinum (13% Rhodium), Platinum	0 to 1480	12μV/°C	oxidizing, inert

TABLE 3: *The most common thermocouple types are shown with their standardized material and performance specifications. These thermocouple types are fully characterized by the American Society for Testing and Materials (ASTM) and specified in IST-90 units per NIST Monograph 175.*
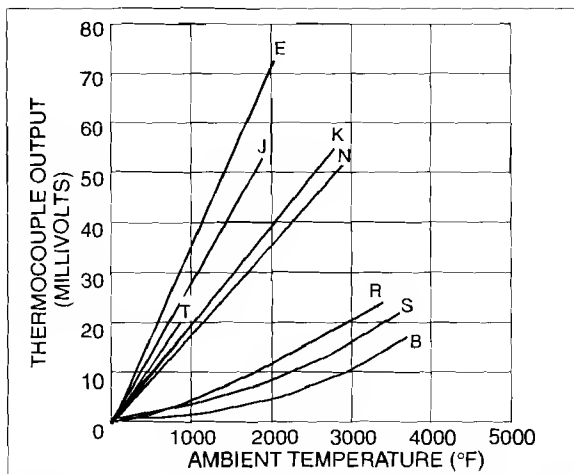
FIGURE 2: *Thermocouples are sensitive to a wide range of temperatures making them appropriate for a variety of hostile environments.*

c_0	$-1.7600413686 \times 10^{-2}$
c_1	$3.8921204975 \times 10^{-2}$
c_2	$1.8558770032 \times 10^{-5}$
c_3	$-9.9457592874 \times 10^{-8}$
c_4	$3.1840945719 \times 10^{-10}$
c_5	$-5.6072844889 \times 10^{-13}$
c_6	$5.6075059059 \times 10^{-16}$
c_7	$-3.2020720003 \times 10^{-19}$
c_8	$9.7151147152 \times 10^{-23}$
c_9	$-1.2104721275 \times 10^{-26}$

TABLE 4: *These are the Type K thermocouple coefficients that can be used to linearize the output voltage results for a temperature range of 0°C to 1372°C. These coefficients are used in the equation $V = c_0 + c_1t + c_2t^2 + c_3t^3$ ... where V is equal to the voltage across the thermocouple junction, and t is equal to the temperature.*

At the time of shipment, the thermocouple performance is guaranteed by the vendor in accordance with NIST 175 standards (adopted by ASTM). These standards define the temperature behavior of the thermocouple as well as the quality of the material used.

Thermocouples are extremely non-linear when compared to RTD, Thermistor, and Integrated Silicon Sensors. Consequently, complex algorithms must be performed with the processor portion of the circuit. An example of the complexity of the calculation is shown in Table 4. These are the Type K Thermocouple coefficients that can be used to linearize the output voltage results for a temperature range of 0°C to 1372°C. These coefficients are used in the equation

$$V = c_0 + c_1 t + c_2 t^2 + c_3 t^3 ...$$

where
V is equal to the voltage across the thermocouple junction, and

t is equal to the temperature.

The alternative to using these complex calculations is to use program memory for a look-up table. The replacement look-up table for the equation coefficients of the Type K thermocouple in Table 4 is approximately an 11 x 14 array of decimal integers ranging from 0.000 to 13.820.

Additionally, the thermocouple can quantify temperature as it relates to a reference temperature. The reference temperature is defined as the temperature at the end of the thermocouple wires furthest from the soldered bead. This reference temperature is usually sensed using an RTD, Thermistor, or Integrated Silicon Sensor.

The thermal mass of the thermocouple is smaller than the RTD or Thermistor, consequently the response of the thermocouple as compared to larger temperature sensors is faster. The wide temperature ranges of the sensor makes it exclusively appropriate for many hostile sensing environments.

Thermocouple Error Analysis

Thermocouples are generally low cost, rugged and available in smaller sizes than the other temperature sensors. Any stress on the material due to bending stretching or compression can change the characteristics of the thermal gradients. Additionally, corrosive material can penetrate the insulation material and cause a change in the thermal characteristics. It is possible to encase the thermocouple bead in protective tubing such as a ceramic tube for high temperature protection. Metallic wells can also provide mechanical protection.

The thermocouple voltage drop occurs along the temperature gradient down the length of the two dissimilar metals. This does not imply that shorter versus longer wires will necessarily have differing Seebeck Coefficients. With shorter wires, the temperature gradient is simply steeper. However, the longer wires do have an advantage in terms of conduction affects. With the longer wires the temperature gradient is lower and conduction losses are reduced.

On the down side, these types of temperature sensors have a very low output signal. This places additional requirements on the signal conditioning circuitry that follows the thermocouple. In addition to this low level output signal, the linearity of the device requires a considerable amount of calibration. This calibration is typically done in firmware as well as software. In firmware, an absolute temperature reference is needed which serves as a "cold junction" reference. In software, the linearity errors of the thermocouple are reduced with look-up tables or high order polynomial equations. And finally, EMI signals are easily coupled in to this two-wire system.

Lower gage wires are required for higher temperatures and will also have a longer life. However, if sensitivity is a prime concern, larger wire gages will provide better measurement results.

To summarize, thermocouples are usually selected because for the wide temperature range, ruggedness, and price. Accuracy and good linearity are hard to achieve in precision systems. If high accuracy is desirable, other temperature sensors may be a better alternative.

THE RTD IS ABSOLUTELY AN ALTERNATIVE

RTD element technologies are constantly improving, enhancing the quality of the temperature measurement. To produce a high quality, accurate temperature measurement system, the selection of the RTD element is critical. The RTD (Resistance Temperature Detector) is a resistive element constructed from metals, such as, Platinum, Nickel or Copper. The particular metals that are chosen exhibit a predictable change in resistance with temperature. Additionally, they have the basic physical properties that allow for easy fabrication. The temperature coefficient of resistance of these metals is large enough to render measurable changes with temperature.

Other temperature sensing devices, such as thermocouples, fall short of giving the designer an absolute result that is fairly linear over temperature. The linear relation between resistance and temperature of the RTD simplifies the implementation of signal conditioning circuitry. The resistance change to temperature of each of these types of RTDs is shown in Table 5. Platinum RTDs (PRTD) are the most accurate and reliable of the three types shown in Table 5.

Of all the material types, Platinum RTDs are best suited for precision applications where absolute accuracy and repeatability is critical. The platinum material is less susceptible to environmental contamination, where copper is prone to corrosion causing long term stability problems. Nickel RTDs tolerate environmental conditions fairly well, however, they are limited to smaller temperature ranges.

The PRTD has nearly linear thermal response, good chemical inertness and is easy to manufacture in the form of small-diameter wires or films. As shown in Table 5, the resistivity of the platinum is higher than the other metals, making the physical size of the element smaller. This offers advantages where "real-estate" is at a premium as well better thermal responsiveness.

Thermal responsiveness of an RTD affects the measurement time. It is also dependent on the housing material of the RTD and the size of the implementation of the RTD element. Elements with smaller dimensions can be housed in smaller packages. Since RTD are typically smaller, their thermal response times can be shorter than silicon based temperature sensors.

The absolute, 0°C value of the element is available in a wide range of resistances and can be specified by the user. For instance, the standard resistance of a platinum RTD (PRTD) is 100Ω. But, they are also available as 50, 100, 200, 500 1000 or 2000Ω elements.

As stated before, the RTD is an absolute temperature sensing devices as opposed to the thermocouple, which senses relative temperatures. Consequently, additional temperature sensors would not necessarily enhance the accuracy of the system.

RTD Detector Material	Thermal Response (at 0°C)	Typical Material Resistivity (at 0°C)
Platinum	0.00385 $\Omega/\Omega/°C$ (IEC 751)	9.81×10^{-6} Ω cm
Nickel	0.00672 $\Omega/\Omega/°C$	5.91×10^{-6} Ω cm
Copper	0.00427 $\Omega/\Omega/°C$	1.53×10^{-6} Ω cm

TABLE 5: *RTD temperature sensing devices are available in a variety of materials. The temperature coefficient of these devices is specified in terms of ohms, per ohms per °C.*

In most applications, linearization is not required. Table 6 shows the temperature versus resistance of a 100 Ω platinum RTD. With a 100Ω PRTD, the change in resistance from 0°C to 100°C changes resistance by:

$$\Delta R = (Thermal\ Response) \times R_0 \times \Delta t$$

$$\Delta R = 0.00038\,\Omega/\Omega/°C \times 100\,\Omega \times 100\ °C$$

$$\Delta R = 38.5\Omega$$

The accuracy of the PRTD over its temperature range is also shown in terms of $\Delta°C$ from ideal.

Of the temperature sensors discussed in this application note, the RTD is the most linear with only two coefficients in the linearization equation,

$$R_t = R_0(1 + At + Bt^2)$$

for temperatures 0 °C to 859 °C

$$R_t = R_0(1 + At + Bt^2) + C(t - 100t^3)$$

for temperatures -200°C to 0°C
where
R_t is the resistance of the RTD at measurement temperature,
t is the temperature being measured,
R_0 is the magnitude of the RTD at 0°C,
A, B and C are calibration coefficients derived from experimentation.

These equations are solved after five iterations making it possible to resolve to ±0.001°C of accuracy.

RTD Error Analysis

Beyond the initial element errors shown in Table 6 there are other sources of error that effect the overall accuracy of the temperature sensor. The introduction of defects into the mechanical integrity of the part such as bending the wires, shock due to rough handling, constriction of the packaging that leads to stress during thermal expansion, and vibration can have a long term effect on the repeatability of the sensor.

Although the mechanical stresses can effect long term stability, the electrical design used to condition, gain and digitize the RTD output can also effect the overall accuracy. One of these sources of errors is the self heating of the RTD element that results from the required current excitation. A current excitation is used to convert the resistance of the RTD into a voltage. It is desirable to have a high excitation current through the resistive sensing element in order to keep the output voltage above the system noise levels. A negative side to this design approach is that the element will self-heat as a result of the higher current. The combination of current and resistance create power and in turn the by-product of heat. The heat generated by the power dissipation of the element artificially increases the resistance of the RTD.

The error contribution of the heat generated by the element's power dissipation is easily calculated given the package thermal resistance ($\theta_{PACKAGE}$), the magnitude of the current excitation and the value of the RTD resistance (R_{RTD}).

Temperature (°C)	Typical Absolute Resistive Value (Ω)	Deviation in Ω	Deviation in °C
-200	23.0	± 0.56	± 1.3
-100	61.5	± 0.32	± 0.8
0	100.0	± 0.12	± 0.3
100	138.5	± 0.30	± 0.8
200	177.0	± 0.48	± 1.3
300	215.5	± 0.64	± 1.8
400	254.0	± 0.79	± 2.3
500	292.5	± 0.93	± 2.8
600	331.0	± 1.06	± 3.3
700	369.5	± 1.17	± 3.8
800	408.0	± 1.28	± 4.3

TABLE 6: *OMEGA Platinum Resistance Elements Allowable Deviation from Ideal Values for a 100Ω Sensor. The PRTD in this illustration is manufactured to have a thermal response of 0.00385Ω/Ω / °C (IEC 751) near 0°C, Class B.*

For example, if the package thermal resistance is 50°C/W, the RTD's nominal resistance is 250Ω, and the element is excited with a 5mA current source, the artificial increase in temperature (Δ °C) as a result of self heating is:

$$\Delta \, \mathcal{C} = I^2 R_{RTD} * \theta_{PACKAGE}$$

$$\Delta \, \mathcal{C} = (5mA)^2 \, x \, 250\Omega \, x \, 50 \, °C/Watt$$

$$\Delta \, °C = 0.3125 \, °C$$

This example illustrates the importance of keeping the magnitude of current excitation as low as possible, preferably less than 1mA.

A second source of error resulting from the electrical design comes from the lead wires to and from the sensing element. The technique used to connect the RTD to the rest of the circuit can be a critical issue. Three possible wire configurations can be used when connecting the element to the remainder of the circuit. In Figure 3a. the 2-wire configuration is by far the least expensive, however, the current that is used to excite the RTD element flows through the wires as well are the resistive element. A portion of the wires are exposed to the same temperatures as the RTD. The effects of the wire resistance change with temperature can become a critical issue.

For example, if the lead wire is constructed of 5 gage copper leads that are 50 meters long (with a wire resistance of 1.028Ω/km), the contribution of both wires increases the RTD resistance by 0.1028Ω. This translates into a temperature measurement error of 0.26°C for a 100Ω @ 0°C RTD. This error contributes to the non-linearity of the overall measurement. The least accurate of configurations shown in Figure 3 is the 2-wire. Circuits can be configured to effectively use the 3-wire and 4-wire configuration to remove the error contribution of the lead wires completely.

a.) Two-wire RTD
less accurate

b.) Three-wire RTD
most used

c.) Four-wire RTD
most accurate
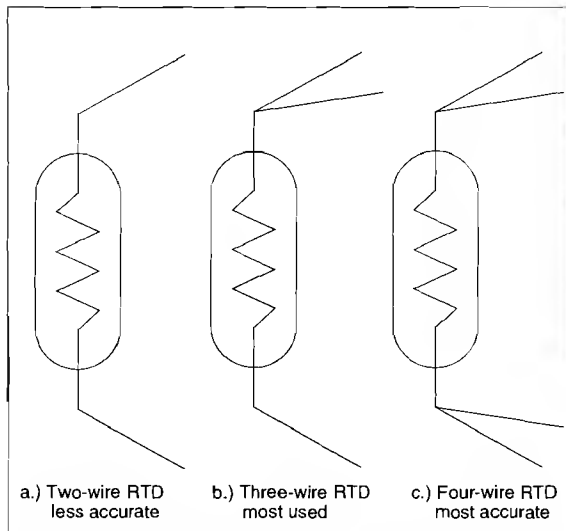
FIGURE 3: *RTD elements are available in two-wire, three-wire or four-wire configurations. Two-wire RTDs are the least accurate because the contribution of the wire resistance and wire resistance drift to the measurement. With four-wire RTDs, this error can be eliminated by using force and sense techniques in the circuit design.*

GET THE GREAT ACCURACY OF THE THERMISTOR

If accuracy is a high priority, the thermistor should be the temperature sensor of choice. Thermistors are available in two varieties, NTC and PTC. The NTC (negative temperature coefficient) thermistor is constructed of ceramics composed of oxides of transition metals (manganese, cobalt, copper, and nickel). With a current excitation the NTC has a negative temperature coefficient that is very repeatable and fairly linear. These temperature dependent semiconductor resistors operate over a range for –100°C to 450°C. Combined with the proper packaging, they have a continuous change of resistance over temperature. This resistive change versus temperature is larger than the RTD (see Figure 4), consequently the thermistor is systematically more sensitive.
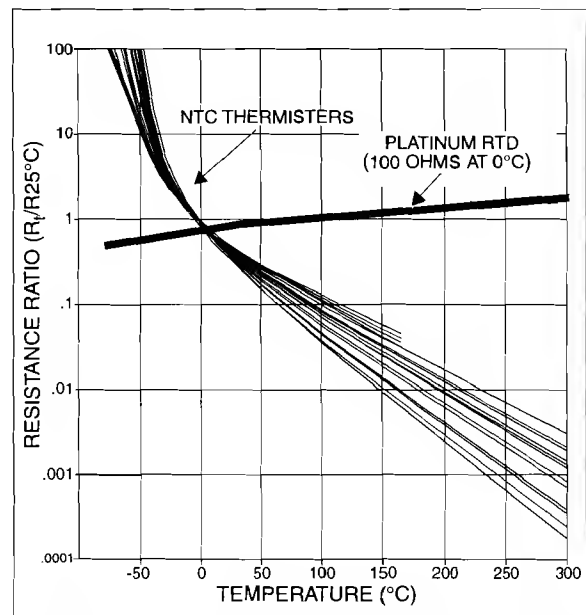
FIGURE 4: *The temperature response versus resistance of the NTC thermistor and the RTD.*

The temperature characteristics of a typical NTC thermistor along with a 100Ω RTD is shown in Figure 4. In this figure, the difference between the temperature coefficients of these two sensors is noticeable. The thermistor has a negative temperature coefficient as expected and the absolute value of the sensor changes by 10,000 times over its usable temperature range. In contrast, the RTD shown has a positive temperature coefficient and only changes by four times over is usable temperature range. This higher sensitivity of the thermistor makes it attractive in terms of accuracy in measurements.

The Thermistor is less linear than the RTD in that it requires a 3rd order polynomial for precise temperature corrections. The linearity equations for the Thermistor are:

$$In \ R_T = B_0 + \frac{B_1}{T} + \frac{B_2}{T^2} + \frac{B_3}{T^3}$$

over the entire temperature range

where

B_X are the material constants of the thermistor

This linearization formula can resolve to a total measurement uncertainty of ±0.005°C. However, it is tedious when implemented in the microcontroller. Alternatively, look-up tables can be generated to serve the same purpose with slightly less accuracy.

Thermistor Error Analysis

Although the NTC thermistor has the capability of being more accurate than the RTD temperature sensor, the two sensors have many things in common. They are both temperature sensitive resistors.

When using the thermistor, an error due to overheating is easily created. As a matter of fact, more care is required when designing the excitation of the thermistor because the thermistor resistive values are usually higher than the RTD. Take for example, a package thermal resistance of 10°C/W (bead diameter of 14mils), a nominal Thermistor resistance is 10kΩ @ 25°C with the Thermistor excitation of 5mA. The artificial increase in temperature (Δ°C) as a result of self heating is:

$$\Delta \ °C = I_2 R_{THERMISTOR} \ x \ \theta_{PACKAGE}$$

$$\Delta \ °C = (5mA)^2 x \ 10k\Omega \ x \ 10 \ °C/Watt$$

$$\Delta \ °C = 2.5 \ °C$$

With temperature changes of this nature, the measurement is obviously inaccurate, but also the thermal coefficient of the thermistor material delays the full effect of the problem for several seconds as the package material stabilizes. To complicate this thermal effect further, the thermal heating of the thermistor decreases the thermistor resistance (instead of the increase seen with the RTD). Since the thermistor has a negative resistive coefficient, the overheating effect reverses as the thermistor resistance becomes less than the voltage across the thermistor divided by the excitation current. This phenomena is not easily overcome with software calibration and should be avoided.

The PTC thermistor has a positive temperature coefficient and is constructed from barium titanate. The sensitivity of the PTC is considerably higher than the sensitivity of the NTC thermistor and should be used when a specific temperature range is of interest (-25 to 150°C). Over the lower portion of the resistance versus temperature curve the thermistor resistance if fairly constant. At higher temperatures the material passes through a threshold temperature (between 80°C and 140°C, dependent on chemical composition of the ceramic) where the resistance versus temperature characteristics change dramatically (Figure 5).

At this point, increases in temperature cause a rise in the PTC's resistance and the PTC resistive / temperature characteristics become very steep.

A second type of PTC thermistor is known as the Silistor. This device is constructed of a thermally sensitive silicon material and also has a positive temperature coefficient (-60°C to 150°C) that is linear over the entire operating range.

Both of the thermal characteristics of the PTC type thermistors are shown in Figure 5.
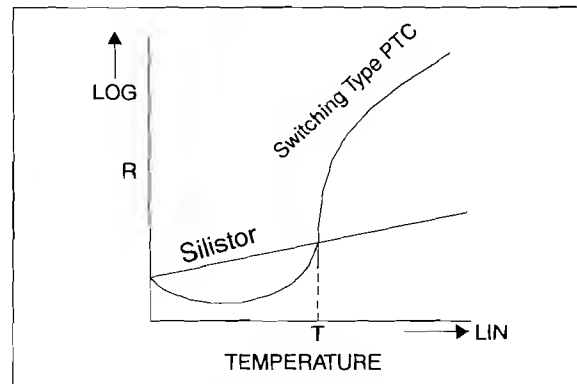
FIGURE 5: PTC thermistor and silistor resistance versus temperature response.

SELECT THE EASY TO USE INTEGRATED SILICON TEMPERATURE SENSOR

The integrated circuit temperature sensors offer another alternative to solving temperature measurement problems. The advantages of integrated circuit silicon temperature sensors include, user friendly output formats and ease of installation in the PCB assembly environment.

Since the silicon temperature sensor is an integrated circuit, integrated circuit designs can be easily implement on the same silicon as the sensor. This advantage allows the placement of the most challenging portions of the sensor signal conditioning path to be included in the IC chip. Consequently, the output signals from the sensor, such as large signal voltages, current, or digital words, are easily interfaced with other elements of the circuit. As a matter of fact, some integrated silicon sensors include extensive signal processing circuitry, providing a digital I/O interface for the microcontroller.

On the other hand, the accuracy and temperature range of this sensor does not match the other types of sensors discussed in this application note. A temperature sensor IC can operate over a nominal temperature range of −55 to 150 °C. Some devices go beyond this range, while others operate over a narrower range.

CHOOSE THE RIGHT TEMPERATURE SENSOR

Of the temperature sensors on the market today, the thermocouple, RTD, Thermistor, and Integrated Silicon Sensors are continuing to dominate. The thermocouple is most appropriate for higher temperature sensing, while the RTD is best suited for lower temperatures were good linearity is desirable. The Thermistor is typically used for applications with smaller temperature ranges, but it offers greater accuracy than the thermocouple or the RTD.

All four of the sensors mentioned in this application note have the capability of providing good, accurate, and reliable performance, making the final sensor selection appear somewhat trivial. However, once the temperature sensor has been selected, the next step is to design the analog and digital signal conditioning circuit. The design of this circuit will determine the actual performance that is finally achieved.

Several application notes can be found in the Microchip's library that elaborate on these circuits. Each of these application notes will present circuit alternatives that take into account simplicity, accuracy and cost.

REFERENCES

Baker, Bonnie, "Low Power Temperature Sensing with Precision Converters", *Sensors*, (February 1997) p 38.

Baker, Bonnie, "Precision Temperature Sensing with RTD Circuits", AN687, Microchip Technology Inc. (1998).

Baker, Bonnie, "Single Supply Temperature Sensing with Thermocouples", AN684, Microchip Technology Inc. (1998).

Baker, Bonnie, "Thermistors in Single Supply Temperature Sensing Circuits", AN685, Microchip Technology Inc. (1998).

Klopfenstein, Rex, "Software Linearization of a Thermocouple", *Sensors*, (December 1997) p 40.

Product Book, *Thermometrics, Inc.* (1997).

Schraff, Fred. "Thermocouple Basics" *Measurement & Control*, (June 1996) p 126.

Sulciner, James, "Understanding and Using PRTD Technology, Part 1: History, Principles and Designs", *Sensors*, (August 1996).

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